FRONTLIT ILLUMINATED TOUCH PANEL

Technical Field

This invention relates to touch panels and to electronic displays.

Background Art

Flat panel displays are typically backlit by light guide slabs (often referred to as "backlights") that provide uniform illumination to a transmissive light valve. The backlight may be the primary light source for the display, or a source of supplemental illumination in a predominantly reflective (often referred to as a "transflective") display. Alternatively, flat panel reflective displays may be front-lit by a light guide slab (often referred to as a "frontlight" or "front light guide") that provides uniform illumination from the viewing side of a reflective light valve. This allows elimination of the backlight and placement of a reflector in the light valve, thereby increasing the display's reflectivity and brightness in well-lit ambient light conditions when the frontlight is turned off. Front light guides should have sufficient clarity so that they do not distort or significantly attenuate the display image. Preferably the front light guide also uniformly illuminates the display at a brightness level sufficient to render the display readable in dark ambient conditions.

Displays may also incorporate touch panels that allow the user to input information via a stylus or finger pressure. For example, a common type of touch panel known as a "resistive overlay" design utilizes two transparent layers with partially conductive coatings separated by spacers. When the layers are pressed together, the electrical resistance is sensed in two dimensions to obtain the coordinates of the contact point. The bottom layer (the layer closest to the display) typically is quite stiff and made of glass. The top layer (the layer that will be touched by the stylus or finger) typically is fairly flexible and made of plastic.

Resistive overlay and other touch panel designs are described in the "Carroll Touch Handbook", available at www.carrolltouch.com. Many such other touch panel designs, including "capacitive overlay", "guided acoustic wave", "surface acoustic wave" and "near field imaging" (see U.S. Patent No. 5,650,597) touch panels, incorporate an optically clear, relatively stiff slab atop the display. Some types of "scanning infrared" touch panels also incorporate an optically clear, relatively stiff slab atop the display. As with resistive overlay designs, glass is most commonly used to form the stiff slab.

Japanese Published Patent Application No. JP 11344695A (equivalent to WO 9963394) shows an integral front light guide and touch panel in which the light guide portion is made of molded plastic. The upper surface of the light guide is bonded to the lower surface of the touch panel using a layer of transparent resin, and the lower surface of the light guide has a polygonal or circular dot pattern formed by an ink of transparent or semi-transparent resin having a higher refractive index than the light transmission plate and containing a photodiffusion pigment. Alternatively, the lower surface of the light guide can be formed with "fine crimps" or with "prisms" (shown as sawtooth projections) formed parallel to the end face of the input of the light transmission plate. The light guide of this reference utilizes scattering by the above-mentioned photodiffusion pigment, or refraction through the above-mentioned crimps or prisms, to extract light from the light guide into a light valve. The sawtooth projections in this reference are oriented with the inclined portion of the sawtooth facing away from the light input end of the light guide.

Japanese Published Patent Application No. JP 2000-47178A shows an integral front light guide and touch panel in which the light guide portion is wedge-shaped and has a pattern of spacers on its upper surface. The light guide of this reference utilizes scattering by the spacers to extract light from the light guide into a light valve.

Other illuminated touch panel display devices are shown in Japanese Published Patent Application Nos. JP 61188515A, JP 11065764A, JP 11110131A, JP 11174972A, JP 11260133A, JP 11316553A, JP 11065764A and JP 2000075293A, and in PCT Published Patent Application No. WO 99/63394A.

U.S. Patent No. 5,396,350 shows a backlight having an array of microprisms that reflect light into a transmissive light valve.

U.S. Patent No. 5,428,468 shows an illumination system employing a waveguide and an array of microprisms that reflect light out of the waveguide. U.S. Patent No. 5,995,690 shows a light extraction tape for coupling light out of a waveguide.

Other illuminated frontlit or backlit illumination or display devices are shown in U.S. Patent Nos. 4,373,282; 4,528,617; 4,751,615; 4,799,137; 4,811,507; 4,874,228; 5,005,108; 5,050,946; 5,054,885; 5,190,370; 5, 341,231; 5,359,691; 5,485,354; 5,506,929; 5,555,109; 5,555,329; 5,575,549; 5,594,830; 5,608,550; 5,608,837; 5,613,751; 5,668,913; 5,671,994; 5,835,661; 5,894,539; 6,011,602 and 6,139,163; and in European Patent Application EP 0 802 446 A1.

Summary of Invention

Typically, touch panel fabrication requires one or more manufacturing steps that involve high temperatures or other harsh processing conditions. For example, many touch panel designs employ a conductive or capacitive layer of indium tin oxide ("ITO"). The processing temperatures required to apply a satisfactory ITO layer will destroy most plastic substrates. The touch panel also should have good optical properties. Thus the touch panel often includes a heat-resistant glass substrate that can support an ITO layer or other heat-processable layers of the touch panel. Such touch panels can be combined with a separate front light guide, which should also have good optical properties, including good light extraction characteristics. The front light guide can be made, for example, from a molded plastic wedge, and the resulting combination placed atop a reflective light valve. This approach employs extra parts, has an extra interface in the supplied light path, and has increased overall thickness. However, such an approach also permits the lower slab of the touch panel to be fabricated from flat glass, which is relatively low in cost and can survive the processing steps required to form a layer of ITO or other applied material.

Although a number of illuminated touch panel devices have been proposed, there is an ongoing need for thinner, more efficient or more evenly illuminated devices, for devices that could be more easily constructed, and for devices with reduced power consumption. Many current devices do not use all of the light supplied by the light

source. If such unused light could be channeled to the display, then power consumption could be further reduced and display brightness could be increased.

Some of the above-mentioned illuminated touch panel devices employ scattering or refraction to extract light from the light guide. These approaches can cause reduction in contrast, or can supply light at less than optimal angles to a light valve in the display.

The present invention provides, in one aspect, a frontlit touch panel for use with a reflective light valve, comprising a front light guide having at least one light input face that supplies light to the guide, a viewing face, a light output face opposite the viewing face, and at least one component of a touch-sensitive transducer, the light output face having a light extraction layer thereon having a substantially flat light exit face and containing buried reflective facets that extract supplied light from the guide through the light exit face. The touch panel can be easily fabricated, for example, by fabricating a component (e.g., a conductive or capacitive layer) of a touch-sensitive transducer on an ordinary flat glass sheet, and by laminating the resulting assembly to a plastic extraction film. An optional top membrane can be applied atop the touch panel, and an optional antireflection coating can be applied to the light exit face of the structured-surface film.

The present invention also provides an illuminated touch panel display comprising:

a) at least one light source;

b) a front light guide having at least one light input face through which light from the source can be supplied to the guide, a viewing face, a light output face opposite the viewing face, and at least one component of a touch-sensitive transducer, the light output face having a light extraction layer thereon having a substantially flat light exit face and containing buried reflective facets that extract supplied light from the guide through the light exit face; and

c) a reflective light valve that receives extracted light from the guide and returns at least some of that light through the viewing face.

Compared to the use of a separate touch panel and front light guide, the frontlit touch panels of the invention can have reduced overall thickness, higher transmission and fewer interfaces. The panels can be fabricated using ordinary flat glass and existing touch panel manufacturing methods and equipment to provide a touch panel having

added functionality. Preferably the frontlit touch panels of the invention have a composite construction comprising a layer of glass and one or more other layers made of different materials (e.g., conductive layers, solder traces, sensors or other touch-sensitive-transducer-related components on one major face of the touch panel, and a microstructured plastic surface and optional antireflection coating on the other major face of the touch panel). Preferred embodiments of the panels efficiently extract supplied light while exhibiting good contrast and low distortion. Because the frontlit touch panel has microstructured reflective optics located between the touch panel and the light valve and because the touch panel can have a smooth viewing face, the frontlit touch panels of the invention are relatively robust and are less likely to be damaged than touch panels having microstructured optical features on the viewing face.

Brief Description of the Drawing

Fig. 1 is a side view of an illuminated frontlit touch panel display of the invention.

Fig. 2 is a simplified side view of the touch panel of **Fig. 1**, showing the general path taken by ambient and supplied light rays.

Fig. 3 is a magnified side view of a portion of the touch panel of **Fig. 1** and **Fig. 2**, showing the structured light extraction layer and the path taken by a supplied light ray.

Fig. 4 is a magnified side view of a portion of an illuminated frontlit touch panel of the invention having a low ratio of plateau length to land length.

Fig. 5 is a magnified side view of a portion of an illuminated frontlit touch panel of the invention having a high ratio of plateau length to land length.

Fig. 6 is a graph showing the relationship between the ratio of plateau length to land length and extraction efficiency.

Fig. 7 is a magnified partial side view showing a source of light leakage.

Fig. 8 is a magnified partial side view showing a source of ghosting.

Fig. 9 is a magnified partial side view showing an extraction structure that can reduce light leakage and ghosting.

Fig. 10 is a magnified partial side view showing a light guide and an extraction structure that can reduce light leakage.

Fig. 11 is an exploded side view of a touch panel and light guide of the invention.

Fig. 12 is an exploded side view of another touch panel and light guide of the invention.

Detailed Description

When terms such as "above", "atop", "upper", "upward", "beneath", "below", "lower" and "downward" are used in this application to describe the location or orientation of components in a display, these terms are used merely for purposes of convenience assuming that the display is viewed with its touch-sensitive surface facing generally upwards. These terms are not meant to imply any required orientation for the completed display or for the path taken by supplied or ambient light in actual use of the completed display. Some of the components of this invention and their relationship to one another can also conveniently be described by comparison to a reference plane. For purposes of this invention, the reference plane will be taken to be the plane formed by (or closely approximating) the light output face of the front light guide, which using the orientation convention described above would be the lower face of the light guide.

Referring now to **Fig. 1**, an illuminated touch panel display generally identified as **10** is shown in schematic form. Supplied (in other words, non-ambient) light from source **42** will enter coupler **44,**where it typically is converted from a point source or sources to a line source suitable for use in illuminated touch panel display **10**. The supplied light then enters light input face **14** of front light guide **12**, and as explained in more detail below in **Fig. 2** and **Fig. 3** passes down into and then back up out of reflective light valve (in this case a reflective LCD) **36**. Light guide **12** also has opposing end **15**, light output face **16** and viewing face **18**. An optically transparent adhesive (not shown in **Fig. 1**) fastens structured light extraction layer **32** to light output face **16** of light guide **12**.

Viewing face **18** and flexible membrane **26** have respective conductive coatings **20** and **24**. Coatings **20** and **24**, spacers **28** and flexible membrane **26** form a touch-sensitive transducer **23** that can provide an indication of a command or a position on viewing face **18** when a digit, stylus or other suitable instrument is used to press downward on flexible membrane **26**. Associated electronics (not shown in **Fig. 1**) can be

used to interpret the touch location on viewing face **18**, and to provide electronic signals to control or otherwise influence other electronic devices or components.

Light guide **12** and layer **32** form the remaining portion **21** of illuminated resistive touch panel/front light guide assembly **22**. An air gap **35** separates the lower face **33** of layer **32** from polarizer **38**, which lies atop reflective LCD **36**. Reflective layer **40** is located on the bottom of reflective LCD **36**, and (assuming that reflective LCD **36** is suitably modulated to permit the passage of light) serves to return light that passes from assembly **22** through reflective LCD **36** back towards assembly **22**.

The illuminated touch panel shown in **Fig. 1** employs a resistive touch-sensitive transducer. Those skilled in the art will appreciate that other types of touch-sensitive transducers can be used in the invention. For example, the touch-sensitive transducer can operate via a contact mechanism such as capacitive overlay, guided acoustic wave, surface acoustic wave or near field imaging. The touch-sensitive transducer can also operate via a non-contact mechanism such as a scanning infrared sensor, e.g., via provision of a suitable array of light beams and photosensors above or below the upper face of the light guide. Those skilled in the art will also appreciate that a variety of touch-sensitive transducer components can be employed in the present invention, and that the touch-sensitive components need not involve a conductive layer made of ITO or other heat-processed material.

Referring now to **Fig. 2**, light rays such as supplied light ray **45** from source **42** are reflected towards the opposite end **15** of light guide **12** by total internal reflection off face **18**. Upon striking light output face **16** at a suitable angle, light ray **45** will pass into structured light extraction layer **32**. If a facet (not shown in **Fig. 1** or **Fig. 2**) of layer **32** is struck at a suitable angle by light ray **45**, light ray **45** will be reflected from the facet, exit through the lower face **33** of layer **32** and thereby be extracted from light guide **12**. The extracted light will pass through air gap **35**, and then enter polarizer **38** and reflective LCD **36**. Assuming that reflective LCD **36** is suitably modulated to transmit light, light ray **45** will pass into reflective LCD **36**, strike reflector **40**, be reflected back through reflective LCD **36** and polarizer **38** into layer **32** and light guide **12**, and exit light guide **12** through viewing face **18** (passing through coatings **20** and **24** and membrane **26**), whereupon light ray **45** can be seen by viewer **48**.

If the ambient light level is sufficiently high, then information conveyed by illuminated touch panel display **10** can be seen by viewer **48** without the need for illumination by light source **42**. Ambient light rays such as ambient ray **50** enter illuminated touch panel display **10** through membrane **26**, pass through the various components and layers mentioned above, and (assuming that reflective LCD **36** is suitably modulated) strike reflector **40** and are reflected back through reflective LCD **36** towards viewer **48**.

In illuminated touch panel display **10**, supplied light from light source **42** is guided between two generally parallel faces **16** and **18** within the lower portion **21** of touch panel assembly **22**. The light guide need not have generally parallel faces. However, because faces **16** and **18** of the light guide shown in **Fig. 1** and **Fig. 2** are generally parallel, light guide **12** can be made from a low cost, durable material such as plate glass. Conductive layers, solder traces or other touch-sensitive transducer components can be formed on the first major face of light guide **12**. The light extraction layer, optional antireflection coating and other optional light management features or layers can be formed on the second major face of light guide **12**. Owing to the relatively harsh processing conditions typically required to form such touch-sensitive transducer components, the touch-sensitive transducer components preferably are completely formed on the first major face of light guide **12** prior to formation of the light extraction layer and other optional features or layers on the second major face of light guide **12**.

Referring to **Fig. 3**, a portion of the illuminated front light touch panel display of **Fig. 1** and **Fig. 2** is shown in a magnified side view. Light extraction layer **32** has a light exit face **33** and an upper surface having a plurality of projections such as projections **52** and **53** that face or point toward (and preferably optically contact) light guide **12**. Face **33** is "substantially flat", that is, face **33** is sufficiently flat to avoid inducing objectionable distortion in display **10**. The upper surface of layer **32** is "structured", that is, it has a non-planar topography having finely-shaped features (such as projections **52** and **53**) that can affect the direction or intensity of light rays that strike the upper surface of layer **32**. Projections **52** and **53** are flanked by land portions such as lands **60a** and **60b**, and by enclosed pockets such as pockets **58a** and **58b** containing a medium (e.g., air) having a lower refractive index than the material from which layer **32** is

manufactured. The projections have riser, plateau and facet portions such as riser **54a**, plateau **55a** and facet **56a**. For purposes of discussion, projections such as projections **52** and **53** can be referred to as "generally trapezoidal", even though the projections have only three sides and even though a quadrilateral formed by drawing an imaginary line to complete the fourth side of a projection might not have two parallel sides.

The plateaus are laminated to light guide **12** using transparent adhesive **50**. Plateau **55a** lies against adhesive **50** and is generally coplanar with the other plateaus of layer **32**. Facets such as facet **56a** are "buried" in light extraction layer **32**, that is, such facets lie within layer **32**, between light output face **16** of light guide **12** and light exit face **33** of layer **32**. Riser **54a** adjoins plateau **55a**, which in turn adjoins facet **56a**. Preferably (disregarding for the moment any intervening layer of transparent adhesive), the facets are adjacent to or very near light output face **16** and spaced more remotely from light exit face **33**.

Facets such as facet **56a** are oriented so that light from the input face of light guide **12** such as supplied light ray **46** can pass through adhesive **50** and plateau **55a**, strike facet **56a**, be reflected downwards and thereby be extracted from light guide **12** through exit face **33**. The supplied light is thus extracted from the light guide using reflective optics. Many of the illuminated touch panel assemblies that have heretofore been proposed employ an extraction mechanism that relies on refractive optics, for example by employing a prismatic (e.g., sawtooth) surface on the exit face of the light guide.

Supplied light can be extracted from the light guides of the invention at normal or near-normal angles with respect to the reference plane. In other words, the supplied light can be extracted at a zero or near-zero angle of incidence with respect to the light valve. This can provide improved coupling of extracted light into the light valve compared to light guides that rely on refractive extraction. Using refractive extraction, it is difficult to achieve extraction angles whose centroid is greater than about 40° with respect to the reference plane. In other words, it is difficult to achieve less than about a 50° angle of incidence of the centroid of the extracted light with respect to a normal to the light valve. If the extracted light reaches the light valve at too high an angle of incidence, then the

light valve will not efficiently reflect light toward the viewer, or additional optics (e.g., additional refractive optics) will be required to redirect the extracted light.

An extractor based on reflective optics is less sensitive to variations in wavelength of the supplied light than an extractor based on refractive optics. This can provide improved color uniformity in the illuminated touch panel displays of the invention compared to some illuminated touch panel displays that have heretofore been proposed. Stray reflections, which can lead to objectionable ghosts and loss of contrast, are also less pronounced with reflective extractors compared to refractive extractors. The stray reflections that do arise in reflective extractors tend to be directed away from the viewer. In refractive extractors, some stray reflections tend to be directed towards the viewer, leading to a loss in overall contrast. If such stray reflections are referred to as noise bands, then their presence along the viewing axis represents a source of noise and a loss in signal to noise ratio.

The use of reflective extraction optics in the illuminated touch panels of the invention thus can provide improved design flexibility and performance compared to the use of refractive optics.

Those skilled in the art will appreciate that although lands such as lands **60a** and **60b** are shown in **Fig. 3** as being parallel to the reference plane, they need not be parallel. In addition, risers such as riser **54a** need not be symmetrically inclined with respect to the reference plane. Likewise, facets such as facet **56a** need not be symmetrically inclined with respect to the reference plane.

Those skilled in the art will also appreciate that the projections on light extraction layer **32** can have shapes and orientations other than those shown in **Fig. 3**, so long as proper extraction of light from light guide **12** into reflective LCD **36** takes place. The angle at which supplied light from source **42** enters light guide **12**, and the dimensions, pitch and angular orientation of the projections on light extraction layer **32** preferably are selected so that supplied light is evenly distributed across the viewing face of illuminated touch panel display **10**.

Fig. 4 through **Fig. 6** illustrate the effect of the ratio of plateau length to land length upon overall light output from the bottom of a light guide of the invention. **Fig. 4** shows a magnified side view of a portion of an illuminated touch panel display generally

identified as **70**. Structured light extraction layer **71** has projections such as projection **72** bounded by riser **74**, plateau **76** and facet **78**, and flanked by lands **80a** and **80b**. The total length of all plateaus in layer **71** is less than the total length of all lands in layer **71**, or in other words the ratio of total plateau length to total land length is less than 1:1. Owing to the relatively small overall plateau area of layer **71**, the available extraction window is relatively small and some of the potentially reflective portion of buried facets such as facet **78** may be inaccessible to supplied light rays such as ray **46a**. Accordingly, a smaller fraction of such supplied light rays will be able to reach the facets in layer **71** at a suitable angle so that the supplied rays can be extracted from light guide **12** through exit face **82**, and the overall light output from light guide **12** may be less than desired.

Fig. 5 shows a magnified side view of a portion of an illuminated touch panel display generally identified as **90**. Structured light extraction layer **91** has projections such as projection **92** bounded by riser **94**, plateau **96** and facet **98**, and flanked by lands **100a** and **100b**. The total length of all plateaus in layer **91** is greater than the total length of all lands in layer **91**, or in other words the ratio of total plateau length to total land length is greater than 1:1. Owing to the relatively large plateau area of layer **91**, most or all of the facet area is available for reflection, and supplied light rays such as ray **46b** will be able to reflect from facets in layer **91** and be extracted from light guide **12** through light exit face **99**. Thus the overall light output from the bottom of light guide **12** in the illuminated touch panel of **Fig. 5** will tend to be greater than from the illuminated touch panel of **Fig. 4**.

Fig. 6 is a graph showing the relationship between the ratio of plateau length to land length and light output from the exit face of the light guide. In general, light output (or extraction efficiency) increases as the ratio of plateau length to land length increases, in an approximately logarithmic relationship. Preferably the ratio of total plateau length to total land length is at least 1:1, more preferably at least 3:1. Once the full facet is exposed and accessible to the supplied light rays, the plateau length diminishes in importance and the curve shown in **Fig. 6** levels off. In general, it is preferred for the land length to be greater than zero. For example, if the light extraction layer is formed from a flexible film, then preferably the lands should not be so short that it becomes

difficult to peel away the film from the profiled tooling that typically would be used to make a structured flexible film.

Fig. 7 is a magnified partial side view of an illuminated touch panel **100** of the invention, illustrating a potential source of light leakage. Some light rays such as ray **46c** will be reflected upward via total internal reflection from the lower face **102** of structured light extraction layer **104** towards a buried facet such as facet **103**. At sufficiently low angles of incidence to the facet, light will refracted through the facet, pass through adhesive layer **105** and light guide **108**, and exit the upper face **106** of light guide **108** at a high angle of incidence, away from a typical user's view axis. This light will be lost and will not contribute to the viewer's perception of image brightness.

Fig. 8 is a magnified partial side view of an illuminated touch panel **110** of the invention, illustrating a potential source of ghosting. Some light rays such as ray **46d** will be reflected downward from a facet such as buried facet **111**, be reflected upward from the exit face **112** of structured light extraction layer **114**, pass through adhesive layer **115** and light guide **118**, and exit the upper face **116** of light guide **118**. These light rays will exit light guide **118** at a lower angle of incidence than in the case of light ray **46c** in **Fig. 7**, and can be visible as a ghost image of the illumination source.

Fig. 9 is a magnified partial side view showing an illuminated touch panel **120** of the invention having a structured light extraction layer **124** that can reduce light leakage such as is shown in **Fig. 7**, and an antireflection coating that can reduce ghosting of the type shown in **Fig. 8**. Light rays such as ray **46e** that are reflected upward from the lower face **122** of layer **124** are refracted through buried facet **126** and riser **128**, and then are recaptured by refraction through nearby buried facet **130** and riser **132** back into layer **124**. Light rays such as ray **46f** that are reflected from a facet such as buried facet **126** strike the lower face **122** of layer **124** and pass through face **122** due to the presence of antireflection coating **125** on face **122**.

It is easier to apply a uniform antireflection coating to a flat surface than to a structured surface. Thus it is easier to employ such a coating on the lowermost face (in other words, the light exit face) of the illuminated touch panels of the invention than on the lowermost face of illuminated touch panels that employ refractive optics to extract light through a structured surface on the lowermost face.

Those skilled in the art will appreciate that additional antireflection coating layers or other light management layers or features can be applied to exit face **33**, so long as care is taken preserve the substantially flat topography of exit face **33** and to avoid introduction of undesirable distortions in the viewed image.

Those skilled in the art will also appreciate that more than one light source can be used to supply light to the touch panel displays of the invention. For example, referring again to **Fig. 1**, a plurality of light sources can be placed along light input face **14.** Although not shown in **Fig. 1**, a plurality of light sources could also be placed along end **15**. If light is supplied along both input face **14** and end **15**, then the projections in the structured light extraction layer **32** (e.g., projections such as projections **52** and **53** shown in **Fig. 3**) preferably should be symmetrically oriented with respect to the supplied light from both input face **14** and end **15**. If light is supplied only along input face **14**, then end **15** is preferably equipped with a mirrored surface or other suitable reflector to direct light reaching end **15** back into light guide **12**.

Fig. 10 is a magnified partial side view of an illuminated touch panel **140** having a light guide **142** and a structured extraction layer **144** that can reduce light loss. Light guide **142** is equipped with a specular or diffuse reflector **146** that reflects light such as light ray **46h** back into light guide **142**. The amount of light reaching reflector **146** can be further reduced by tilting or biasing the light source (not shown in **Fig. 10**), so that the axis along which the majority of its light output falls is not parallel to the upper face of light guide **142**. Light rays such as light ray **46g** are reflected downwards from facets such as buried facet **148** and are extracted from layer **144**. Light rays such as light ray **46h** are reflected from reflector **146** back into layer **144** and reflected downward by reflection from facets such as buried facet **150**, which is oppositely inclined from buried facet **148**. These oppositely inclined facets can be repeated along the length of light guide **142**.

Fig. 11 is an exploded side view of an illuminated touch panel **160** of the invention, showing individual layers that can be assembled together. Touch-sensitive transducer layer **161** is formed on the upper face **164** of light guide **162**. Optically transparent adhesive layers **165** and **166** are coated on opposite sides of carrier film **168**, and set aside. Structured light extraction layer **170** is formed from base film **172** and a

light-curable resin using a suitable profiled tool, then cured to form light-cured structured surface **174** atop base film **172**. If desired, an optional antireflection coating (not shown in **Fig. 11**) can be applied to the lower face of base film **172**. This will be especially convenient when structured surface **174** is formed on base film **172** using a continuous method, as the antireflection coating can likewise be applied on the reverse side of base film **172** using a continuous method.

The plateau portions of structured light extraction layer **170** such as plateaus **180a** and **180b** are laminated to adhesive layer **166**, taking care not to damage the structured surface **174** of layer **170** and not to fill the air spaces between projections in layer **170** with adhesive. Adhesive layer **165** can then be laminated to the light output face **163** of light guide **162**. The resulting assembly can conveniently be sold as is, or combined with additional touch panel transducer or display components. For example, the assembly can be combined with the remaining components of a capacitive overlay touch-sensitive transducer (not shown in **Fig. 11**) to provide a touch panel device that can be placed atop a suitable reflective light valve and equipped with a source of supplied light and suitable control electronics. As a further example, optically transparent adhesive layers **165** and **166** could be coated on opposite sides of carrier film **168**, adhesive layer **166** could be laminated to the plateau portions of structured light extraction layer **170**, and the resulting assembly sold as is for later lamination to the light output face of a light guide.

If desired, a more complete assembly can be made by laminating polarizer **176** to the upper face of reflective LCD **182** via adhesive layer **178**. Reflective LCD **182** includes light modulation unit **184** and reflective layer **186**. Other more complete or less complete assemblies can readily be envisioned by those skilled in the art.

Fig. 12 is an exploded side view of another illuminated touch panel **190** of the invention, showing individual layers that can be assembled and fastened to the light output face **193** of light guide **192**. Touch-sensitive transducer layer **191** is formed on the upper face **194** of light guide **192**. Optically transparent adhesive layer **195** is applied to the light output face **193** of light guide **192**. Structured light extraction layer **196** is formed from base film **198** and a light-curable resin using a suitable profiled tool, then cured to form light-cured structured surface **200** atop base film **198**. Structured layer **196** is laminated to adhesive layer **202** and polarizer **204**, taking care not to damage the

structured surface **200** of layer **196** and not to fill the air spaces between projections in layer **196** with adhesive. If desired, an optional antireflection coating (not shown in **Fig. 12**) can be applied to the lower face of base film **198**. The assembly of **Fig. 12** has fewer layers and fewer optical interfaces in the light path than the assembly of **Fig. 11**, but requires somewhat greater care in handling and during lamination.

The light guide can have any desired overall size and thickness but preferably it is as thin as possible, e.g., 5 mm or less. The light guide can be square, rectangular, oval or any other desired shape when viewed from the intended display observation point. The size and shape of the light guide usually will be dictated by the size and shape of the desired display device or desired touch panel. Light guide thicknesses from about 0.1 to about 5 mm are preferred, more preferably about 1 to about 2 mm.

The light guide preferably is an optically suitable material capable of resisting high temperatures and the steps required to fabricate a touch-sensitive surface atop the light guide. As mentioned above, the light guide preferably is substantially planar. If planar, the light guide can be fabricated from ordinary sheet glass. The light input face and viewing face of the light guide can each be generally planar or can have a convex or concave curvature. When the light source is a point or line source, the light input face may be provided with a convex curvature, lenslets, prisms, a roughened surface or other features in order to distribute the incoming light more evenly. The viewing face preferably has an optically smooth finish, in order to minimize transmission losses, undesired scattering and distortion.

The light extraction layer can be fabricated from a wide variety of optically suitable materials including polycarbonate; polyacrylates such as polymethyl methacrylate; and polystyrene, with high refractive index plastics such as polycarbonate being preferred. The light extraction layer preferably is a flexible structured film made by molding, embossing, curing or otherwise forming a moldable resin against a lathe-turned tool or other formed surface, made of metal or other durable material that bears a negative replica of the desired structured surface. Methods for making such formed surfaces and for molding, embossing or curing the extraction film will be familiar to those skilled in the art.

Individual light extraction layer designs can if desired be evaluated without the need for actual layer fabrication, by using suitable ray-tracing modeling software such as "ASAP" from Breault Research Organization, Inc., "Code V" and "Light Tools" from Optical Research Associates, "Optica" from Wolfram Research, Inc. and "ZEMAX" from Focus Software, Inc.

The facets that are present in the light extraction layer (and are buried in the assembled light guide and extraction layer) preferably are sufficiently small so as to be unobtrusive to an ordinary viewer. The configuration, shape and dimensions of the facets and other light management features of the light extraction layer preferably are chosen to maximize extraction efficiency and provide evenly distributed light output at the desired viewing angle.

The projections preferably extend across the full width of the light extraction layer. Although less preferred, the projections can be in the form of shorter, less than full width segments, which can be aligned with one another in rows and columns or staggered from row to row. Rows of projections can be arranged parallel to the light input face or faces or at an angle with respect to the light input face or faces. Most preferably, the projections extend across the full width of the light extraction layer and are generally parallel to the light input face or faces.

In the various embodiments of the invention shown in the Drawing, individual projections in the structured light extraction layers are shown as having the same angular orientation, shape and dimensions from projection to projection. The projections need not all be identical and need not all have the same angular orientation, shape or dimensions. For ease of manufacturing, generally it will be preferred to form a light extraction layer having projections whose riser, plateau and facet segments have the same angular orientation and segment length from projection to projection. The land segments between such projections can if desired also be similar to one another in angular orientation and segment lengths. Preferably however the projections are spaced at a relatively coarser pitch (repeat interval) near the light input face or faces of the light guide, and at a relatively finer pitch further from the light input face. For a light guide illuminated from only one end, this change in spacing can conveniently be accomplished by progressively decreasing the length of the land segments along the length of the light

extraction layer from the light input face to the face at the other end of the light guide. A preferred pitch is from about 0.06 to about 12 projections per mm at the light input face or faces to a maximum of about 250 to about 1 projection per mm further from the light input face or faces.

Those skilled in the art will appreciate that formation of Moiré or other interference patterns can be discouraged or prevented in a variety of ways. For example, the dimensions, angular orientation or spacing of the rows of projections can be adjusted relative to the dimensions, angular orientation or spacing of pixels or other repeating elements in the reflective light valve (e.g., by skewing the direction of the rows of projections a few degrees with respect to the direction of the rows of pixels), so that interference patterns are minimized or eliminated at the viewing face of the display.

Each light extraction layer riser segment preferably is planar although other shapes such as convex or concave shapes can be used if desired. Preferably the facets and other structured surface portions of the light extraction layer are optically smooth, in order to avoid undesirable visual artifacts that may arise due to backscattering of light within the light guide.

The light extraction layer preferably has a thickness of about 20 micrometers to about 500 micrometers, more preferably about 75 to about 125 micrometers. Facet heights (or in other words, land depths) of about 5 to about 50 micrometers are preferred, more preferably about 7 to about 20 micrometers. So long as the facets have sufficient height, the chosen extraction layer thickness has a relatively small effect on extraction efficiency.

Extraction efficiency tends to increase as facet heights increase, as the light guide thickness is reduced, or as the projection pitch decreases. That is, extraction efficiency tends to scale proportionally to (facet height)/[(light guide thickness)*(pitch)]. Put slightly differently, extraction efficiency tends to scale proportionally to the total cross-sectional area of the facets divided by the total cross-sectional area of the light guide input face.

The adhesive layers used to assemble the various layers in the illuminated touch panel displays of the invention can be pressure sensitive adhesives, adhesives cured using energy sources such as heat, UV or electron beam, or any other adhesive having

acceptable optical and mechanical properties. Suitable adhesives and joining techniques will be familiar to those skilled in the art. If desired, one or more of the adhesive layers can be cured after assembly, e.g., by applying the adhesive to one or both of the surfaces to be joined together, mating such surfaces together to form a laminated assembly, and exposing the adhesive layer or layers to suitable curing energy (e.g., UV or e-beam) through one or both sides of the laminated assembly to effect cure.

The adhesive layer between the light guide and the light extraction layer should be applied with care. Such an adhesive can, for example, be applied to the entire light output face of the light guide and the light extraction layer laminated thereto. If desired, the adhesive can be coated atop only the plateau portions of the light extraction layer, and the resulting partially-coated surface laminated to the light output face of the light guide, e.g., as described in U.S. Patent No. 5,545,280. In either case, appropriate care should be taken not to damage the structured surface of the light extraction layer and not to fill the pockets between projections with adhesive.

If desired, the pockets between projections can be filled prior to lamination with a suitable flowable (and preferably hardenable) material having a lower refractive index than the material from which the light extraction layer is made. This can simplify lamination of the light extraction layer to the light guide, and help discourage the adhesive from filling the pockets. However, if the flowable material has a refractive index between that of air and the material from which the light extraction layer is made, then the use of such a flowable material may adversely affect the reflective characteristics of the facets and may reduce overall extraction efficiency compared to the use of air-filled pockets.

The illuminated touch panels of the invention are particularly useful in subminiature or miniature devices illuminated with one or more light emitting diodes (LEDs) powered by small batteries. Suitable devices include cell phones, pagers, personal digital assistants, clocks, watches, calculators, still and video cameras, laptop computers, vehicular displays and the like. The reflective light valves in such devices can be made using a variety of color or monochrome devices. For example, the reflective light valve can be a reflective color LCD such as is used in the COMPAQ iPAQ™ Pocket PC. The reflective light valve can also be a device capable of controlled

frustration of total internal reflection such as the devices described in U.S. Patent No. 6,064,784 and PCT Published Application No. WO 00/75720; a fixed graphic device such as a poster or sign (e.g., a printed menu); or a variable-appearance substrate such as "Gyricon" electronic display material (under development by Gyricon Media Inc.). The illuminated touch panels of the invention can be illuminated with more than one light source, e.g., three or more LEDs. An array of colored light sources (e.g., one or more of each of a red, green and blue LED) can be employed, with the light sources in the array being electronically energized using a continuous or strobed addressing scheme. In addition to LEDs, other suitable illumination sources for the touch panels and displays of the invention include fluorescent or incandescent lamps, electroluminescent lights and the like. A particularly preferred light source for the touch panels of the invention employs the LINEAR ILLUMINATION SOURCE described in copending application Serial No. (attorney's docket no. 56209USA6A.002) filed on even date herewith, the disclosure of which is incorporated herein by reference.

Various modifications and alterations of this invention will be apparent to those skilled in the art without departing from the scope and spirit of this invention. It should be understood that this invention is not limited to the illustrative embodiments set forth above.